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A unified approach to fluid-flow, geomechanical, and seismic modelling

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The perturbations of pore pressure can generate seismicity. This is supported by observations from human activities that involve fluid injection into rocks at high pressure (hydraulic fracturing, CO_2 storage, geothermal energy production) and natural examples such as volcanic earthquakes. Although the seismic signals that emerge during geotechnical operations are small both in amplitude and duration when compared to natural counterparts. A possible explanation for the earthquake source mechanism is based on a number of in situ stress measurements suggesting that the crustal rocks are close to its plastic yield limit. Hence, a rapid increase of the pore pressure decreases the effective normal stress, and, thus, can trigger seismic shear deformation. At the same time, little attention has been paid to the fact that the perturbation of fluid pressure itself represents an acoustic source. Moreover, non-double-couple source mechanisms are frequently reported from the analysis of microseismicity. A consistent formulation of the source mechanism describing microseismic events should include both a shear and isotropic component. Thus, improved understanding of the interaction between fluid flow and seismic deformation is needed.

With this study we aim to increase the competence in integrating real-time microseismic monitoring with geomechanical modelling such that there is a feedback loop between monitored deformation and stress field modelling. We propose fully integrated seismic, geomechanical and reservoir modelling. Our mathematical formulation is based on fundamental set of force balance, mass balance, and constitutive poro-elastoplastic equations for two-phase media consisting of deformable solid rock frame and viscous fluid. We consider a simplified 1D modelling setup for consistent acoustic source and wave propagation in poro-elastoplastic media. In this formulation the seismic wave is generated due to local changes of the stress field and pore pressure induced by e.g. fault generation or strain localization. This approach gives unified framework to characterize microseismicity of both class-I (pressure induced) and class-II (stress triggered) type of events. We consider two modelling setups. In the first setup the event is located within the reservoir and associated with pressure/stress drop due to fracture initiation. In the second setup we assume that seismic wave from a distant source hits a reservoir. The unified formulation of poro-elastoplastic deformation allows us to link the macroscopic stresses to local seismic instability.